

A MECHANISM FOR CONTINUOUSLY RECORDING
THE RATIO OF THE ORDINATES OF TWO CURVES

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TABLE OF CONTENTS

CHAPTER	PAGE
I. STATEMENT OF THE PROBLEM IN GENERAL TERMS	1
Origin of the problem	1
The proposed solution	1
General design considerations	2
Summary	3
II. CONSIDERATION OF THE SYSTEM AS A WHOLE	5
The Input Network	5
The Divider	8
The Curve Tracer	8
Summary	8
III. DESCRIPTION OF CIRCUITS EMPLOYED	10
General considerations	10
The Scanner	12
The Wave Shaper and Integrator	15
The Modulator	18
The Power Amplifier	18
The Divider	21
The Curve Plotter	24
Power Supplies	24
IV. PERFORMANCE AND CONCLUSIONS	28
The Scanner	28
The Wave Shapers and Integrators	28

CHAPTER	PAGE
The Modulators and the Divider	29
Summary	30
BIBLIOGRAPHY	32
APPENDIX A. Test Results	34
APPENDIX B. Operating Instructions	37
APPENDIX C. Maintenance Instructions	40

LIST OF FIGURES

FIGURE	PAGE
1. Wheatstone Bridge	4
2. System Block Diagram	6
3. Photograph of the Input Networks and Divider	11
4. The Scanner	13
5. Voltage Waveforms	14
6. The Wave Shaper and Integrator	16
7. The Modulator	19
8. The Power Amplifier	20
9. The Divider	22
10. Main Power Supply	26
11. Low-Voltage D-C Supplies	27
12a. Performance of Wave Shapers and Integrators	35
12. Main Switch Panel	38

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CHAPTER I

STATEMENT OF THE PROBLEM IN GENERAL TERMS

Origin of the Problem. In the study of chemical substances by means of spectrophotometry, it is necessary to calculate the ratios of the ordinates of two curves, and to plot graphs of these ratios versus the same abscissa as that of the original curves. Since the original curves are generally without equations of a simple form, these ratios must be determined by the point-by-point method. If a reasonable degree of accuracy is desired, it is evident that this method must necessarily be both tedious and expensive.

Work on a device capable of calculating these ratios and plotting the desired curve quickly and automatically was begun in September of 1950 at the suggestion of Dr. William H. Eberhardt of the School of Chemistry.

The Proposed Solution. The proposed computer may be divided into three major components. These divisions comprise:

- A. The Input Networks. Since the curves are the primary sources of information, these networks must convert the curve ordinates into electrical signals which are suitable for positioning the Divider.

- B. The Divider. This device employs the output signals from the Input Networks to compute the desired ratios by means of the Wheatstone Bridge principle.
- C. The Curve Plotter. This device transforms the output of the Divider, a voltage, into the desired ratio graph.

At this point a brief discussion of the Wheatstone Bridge will be given. (See Figure 1) If R_1 and R_2 are in the same ratio as R_3 and R_4 , the output voltage, V_o is zero. (The proof of this statement is given in most texts on d-c circuit theory.) When V_o is equal to zero, the bridge is said to be balanced, and

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \quad (1)$$

so that

$$R_2 = R_4 \frac{R_1}{R_3} \quad (2)$$

Therefore, if R_1 is made proportional to the ordinate of one of the given curves, R_3 is made proportional to the ordinate of the other given curve, and R_2 is adjusted so that the bridge is balanced, the resistance of R_2 is proportional to the ratio of the curve ordinates.

General Design Considerations. The over-all system is subject to the following design considerations:

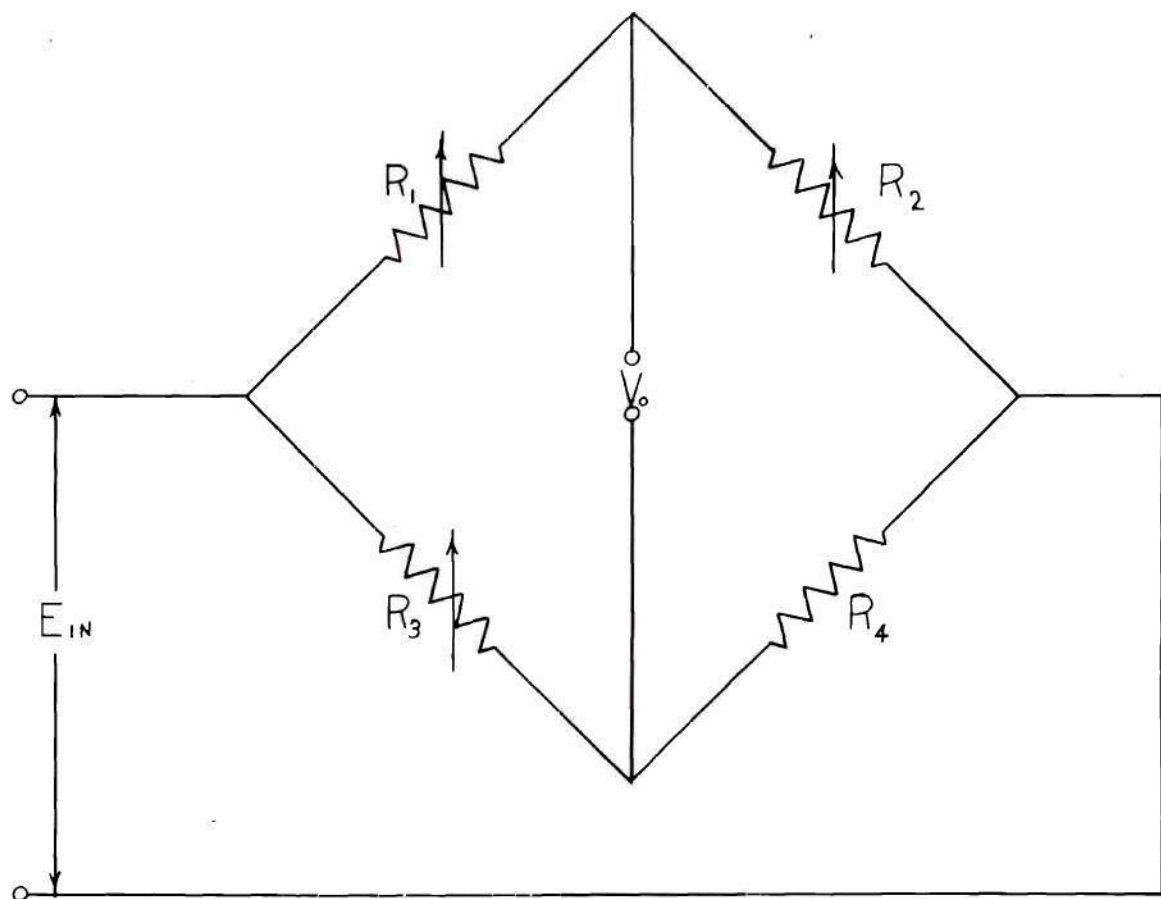
- A. Continuous operation. Since both the input and output of the system are continuous curves, the entire system must operate continuously.
- B. Speed. One of the primary objectives is to save time

in the preparation of the ratio curves. Hence, the machine must plot the desired curve considerably faster than a human computer in order to justify its existence.

- C. Accuracy. The required accuracy will vary with the application. However, the device should be at least as accurate as the input information.

Summary. The operation of the entire system may be described as follows: The Input Networks transform the curve ordinates into electrical signals. These signals are applied to a Divider which calculates their ratio. The output of the Divider actuates the Curve Plotter which plots the desired ratio curve.

FIGURE 1
WHEATSTONE BRIDGE



CHAPTER II

CONSIDERATION OF THE SYSTEM AS A WHOLE

First the entire system is considered without detailed reference to the actual configuration of the individual circuits. The block diagram presented on page 6 may prove helpful during this discussion.

The Input Network. The Input Network consists of an optical Scanner, a Wave Shaper and Integrator, a Modulator, and a Power Amplifier. The function of each of these components is described in the following paragraphs.

The optical scanning system, shown as block No. 1 in Figure 2, contains a light source and a phototube pickup. The light from the source is divided into narrow beams which are swept across the paper, on which the input curve has been plotted, by an electro-mechanical method. This sweep system allows only one beam at a time to traverse the paper. The phototube, which is placed on the opposite side of the paper from the light source, observes the illumination from the scanning beams. If we disregard, for the present, the effect of the coordinate lines on the paper, it is evident that the phototube is illuminated by light of constant intensity except at the instants when the beams are interrupted by the base line and by the curve being scanned. Since the base line, or zero reference line, and the curve serve to block the path of the beams to the phototube, the tube current is momentarily cut off, and the output voltage suddenly rises, when the beams intersect these lines. Consequently it is possible to secure sharp positive impulses of voltage from the Scanner, and the interval between these impulses is proportional to the

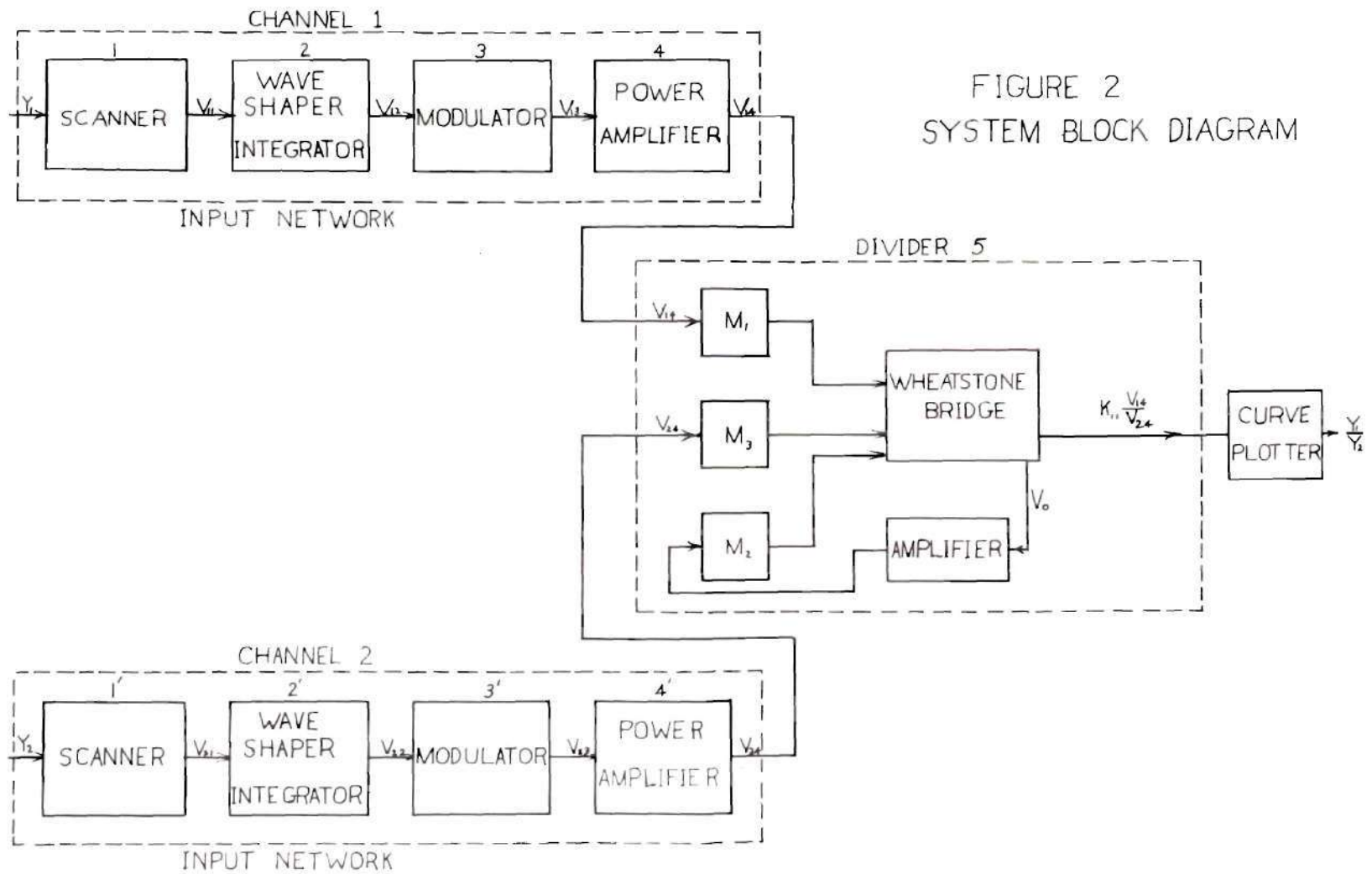


FIGURE 2
SYSTEM BLOCK DIAGRAM

amplitude of the input curve.

As the light beams described above sweep across the curve in the y direction, the curve is moved in the x direction at a constant velocity. In this manner the entire curve is scanned in a very short time.

The output voltage from the Scanner triggers the combined Wave Shaper and Integrator. In this circuit, the voltage impulses from the Scanner are first transformed into square waves of constant amplitude which have their duration, or width, equal to the time between the initiating and terminating impulses. Next, these square waves are integrated. The output of the Integrator, a d-c voltage, is then proportional to the width of the square waves, and hence proportional to the time between the Scanner output impulses.

Block No. 3 contains a Balanced Modulator, a frequency-sensitive Feedback Amplifier, and a Voltage Amplifier. When quiescent conditions prevail, there is a sixty-cycle reference voltage in the Balanced Modulator circuit, but the output of this circuit is zero because the circuit is balanced. However, when the output of the Integrator is applied to one side of the Modulator, an unbalanced condition is created, and an alternating output voltage is produced.

The Feedback Amplifier serves as a band-pass filter which passes the sixty-cycle component of the Modulator output voltage, but eliminates the harmonic content of this voltage.

The Voltage Amplifier raises the amplitude of the sixty-cycle voltage.

The Power Amplifier, block No. 4, raises the power level to that which is sufficient to drive the positioning motors in the dividing networks.

The Divider. Block No. 5 contains the Divider which computes the desired ratios. The basic dividing network is the Wheatstone Bridge discussed in Chapter I. The resistors R_1 , R_2 , and R_3 are potentiometers which are positioned by the drive motors M_1 , M_2 , and M_3 respectively. The motors M_1 and M_3 are driven by the output voltages from the Power Amplifiers, and the motor M_2 is driven by a feedback voltage which is derived from the output of the bridge, V_o . The output voltage of the Divider is proportional to the resistance of R_2 . The method of securing this output voltage is discussed in the following chapter.

The Curve Tracer. The main component of the Curve Tracer is a recorder which plots a curve whose amplitude is determined by the magnitude of a d-c input potential. In this case, the input to the recorder is a d-c voltage which is proportional to the output of the Divider. Consequently, the amplitude of the output curve is proportional to the resistance R_2 .

Summary. To recapitulate, the time between the voltage impulses produced by the optical Scanner is proportional to the ordinates of the input curves, and the width of the square waves produced by the Wave Shaper is equal to the time between these impulses. Therefore, calling the width of the square waves T_s , and the ordinates of the curves y_1 and y_2 respectively, T_{s1} is equal to $k_1 y_1$, for Channel 1. Furthermore, the output of the Integrator is proportional to the width of the square waves. Hence, $V_{12} = K_2 T_{s1}$, or $V_{12} = K_1 K_2 y_1$. Moreover, the output of the Modulator is proportional to the Integrator voltage. So, $V_{13} = K_1 K_2 K_3 y_1$. The voltage from the Modulator is amplified and then used to position R_1 . Consequently, $R_1 = K_1 K_2 K_3 K_4 y_1$.

In a similar manner, the resistance R_3 may be shown to be

$$R_3 = K_5 K_6 K_7 K_8 y_2.$$

As mentioned above, the resistance R_2 is proportional to the ratio of the resistances of the other two variable arms when the bridge is balanced. As a result,

$$R_2 = K_9 \frac{R_1}{R_3} = K_9 \frac{K_1 K_2 K_3 K_4 y_1}{K_5 K_6 K_7 K_8 y_2}. \quad (1)$$

Since the output of the Divider is proportional to R_2 ,

$$V_d = K_{10} R_2 = K_{11} \frac{y_1}{y_2}, \quad (2)$$

$$\text{where } K_{11} = \frac{K_1 K_2 K_3 K_4}{K_5 K_6 K_7 K_8} K_9 K_{10}.$$

Consequently, the ordinates of the output curve will contain the scale factor K_{11} . This factor may be made equal to any desired number by proper adjustment of the system. If it is made equal to unity, the ordinate of the output curve will be equal to the ratio of the ordinates of the input curves.

CHAPTER III

DESCRIPTION OF CIRCUITS EMPLOYED

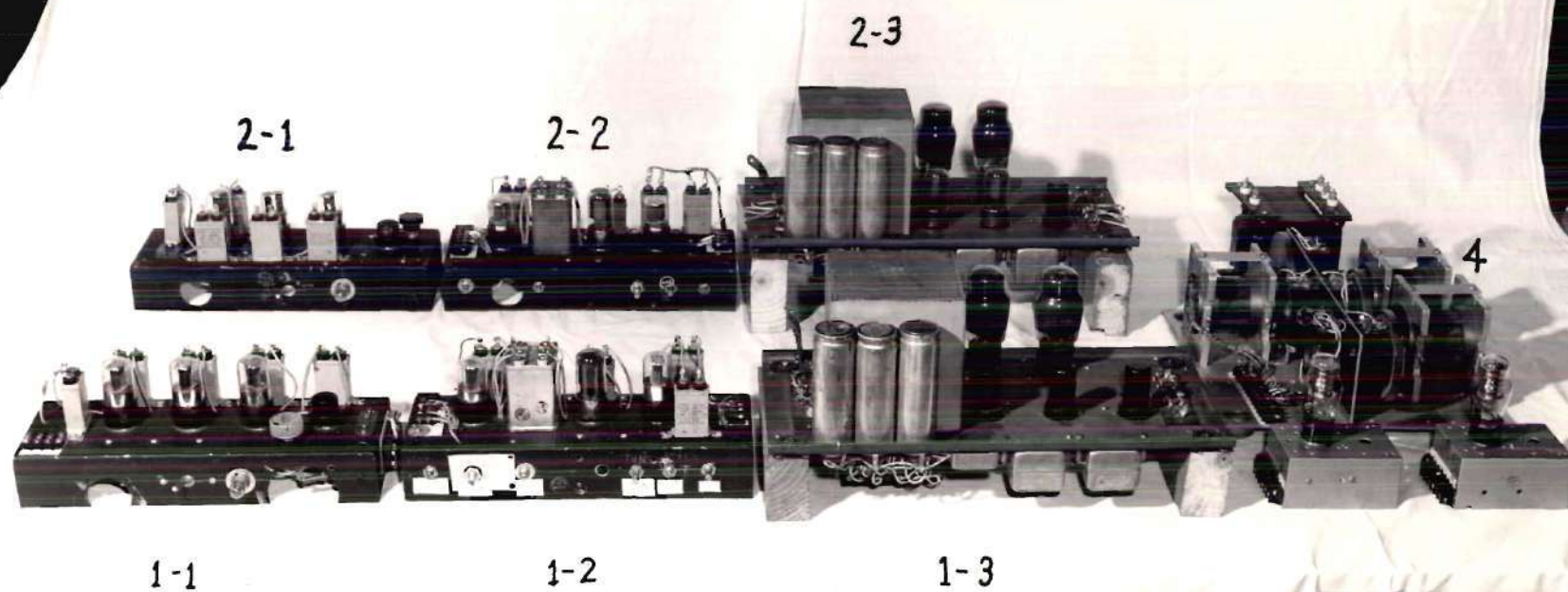
In this chapter, the equipment described in Chapter II is considered in somewhat more detail.

General Considerations. In order to simplify the operation and maintenance of the system as much as possible, the design and construction of circuits were undertaken in accordance with the following general objectives:

- A. Use of standard components.
- B. Minimization of tube types required.
- C. Duplication of circuits where possible.
- D. Construction of "packaged" units on separate chassis to permit easy removal of sections of the system.
- E. Provisions for readjustment of circuits to compensate for the aging of components.

The photograph on Page 11 shows the Input Networks (exclusive of the Scanners) and the Divider. Chassis 1-1 and 2-1 contain the Wave Shapers and Integrators for Channels 1 and 2 respectively. The Modulator units are mounted on Chassis 1-2 and 2-2, and the Power Amplifiers are on Chassis 1-3 and 2-3. Thus it is seen that the Input Networks are separated into three distinct components exclusive of the Scanners, and that each component may easily be removed from the system for inspection or repair. Since the Input Networks are identical for both Channels, the discussion is confined to the operation of the Channel 1 Input Network.

FIGURE 3
INPUT NETWORKS AND DIVIDER



The Scanner. Figures 4(a) and 4(b) show two views of the scanning system, and Figure 4(c) shows the phototube circuit. The mechanical operation of the Scanner is described with reference to these figures.

The light source is enclosed in a metal drum which is rotated by a synchronous motor. The holes around the circumference of the drum form the light into beams which sweep over the paper on which the curve is drawn. The drum is enclosed in a shield in which a narrow slit is cut, thus allowing the light from only one beam to strike the paper at any given instant. Consequently, since the paper is translucent, the phototube is illuminated by light of constant intensity except at the instants when the beam crosses the base line, the curve, and the maximum line.

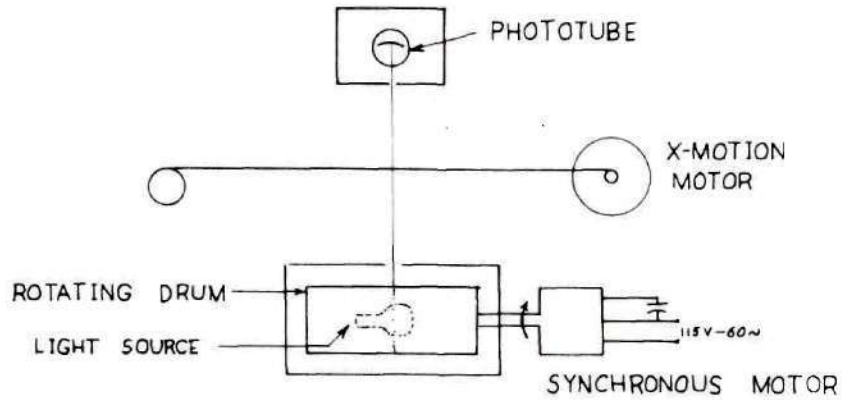
A better understanding of the operation of the Scanner may be gained by an inspection of Figure 5(a). In this figure, the output voltage of the Scanner is shown as a function of time. Suppose that the first pulse occurs when beam number one strikes the base line. Then the second pulse occurs when this beam crosses the curve. Pulse number three is caused by beam number one crossing the maximum line and beam number two crossing the base line simultaneously. The fourth pulse is formed when beam number two crosses the curve, and so on.

It may be seen from the figure that the time between the first and third pulses, the third and fifth pulses, and each pair of succeeding odd-numbered pulses is constant. The magnitude of this constant time T_k , depends on the length of time taken by the beams in sweeping across the paper. For the present scanner, T_k is approximately 0.833 milliseconds.

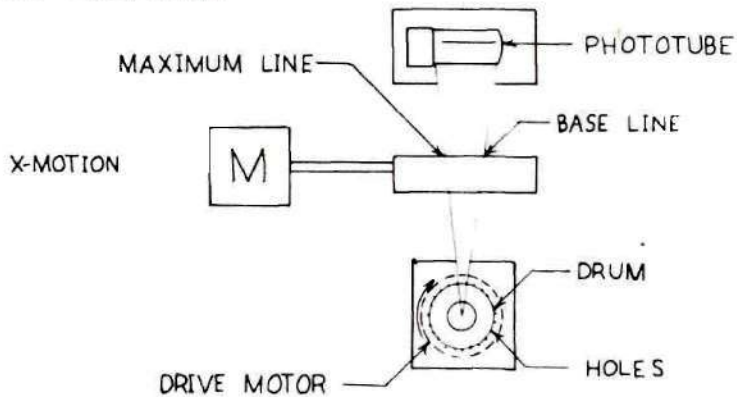
The time intervals T_1 , T_2 , T_3 and T_4 are proportional to the

FIGURE 4
SCANNER

A. SIDE ELEVATION



B. END ELEVATION



C. PHOTOTUBE CIRCUIT

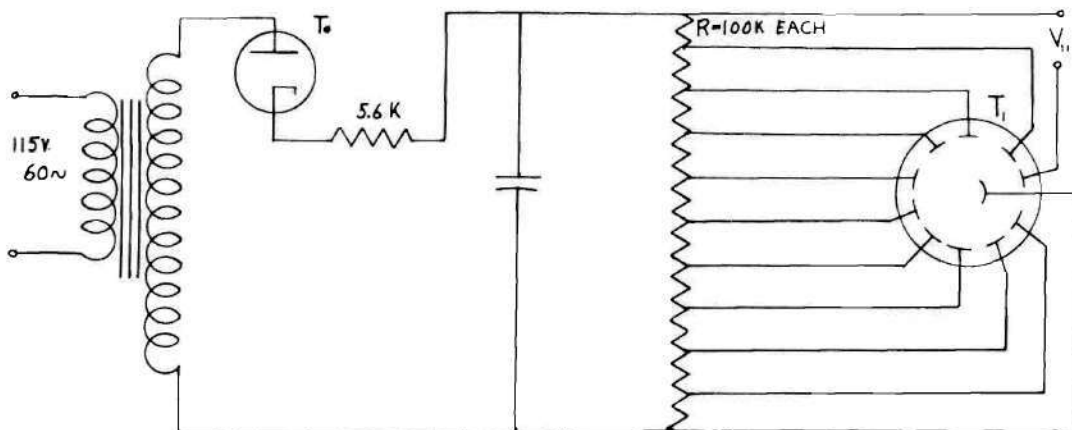
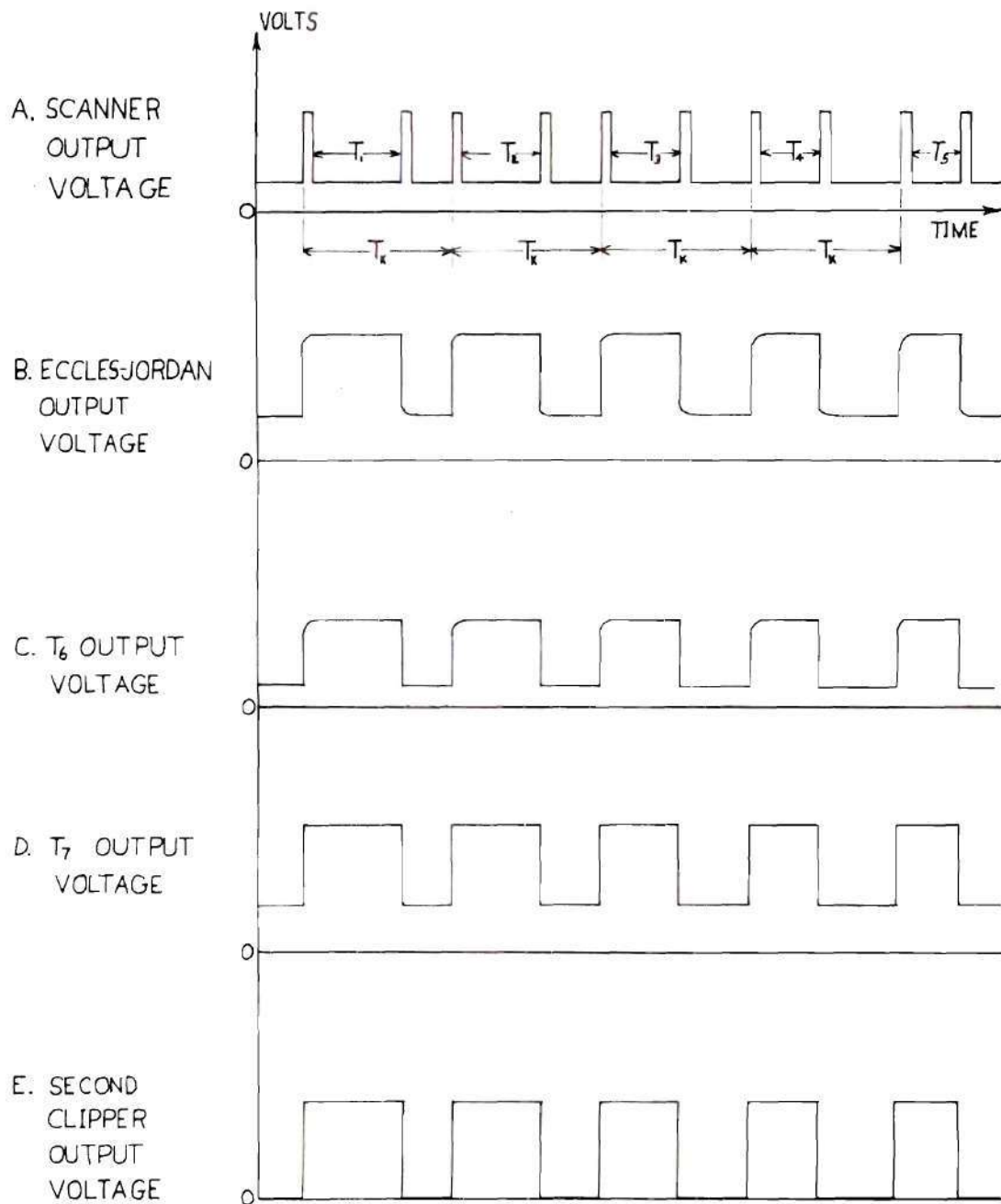


FIGURE 5
VOLTAGE WAVEFORMS



NOT TO SCALE

ordinates of the curve being scanned. For the illustration given in Figure 5(a), the curve amplitude is decreasing as the abscissa increases.

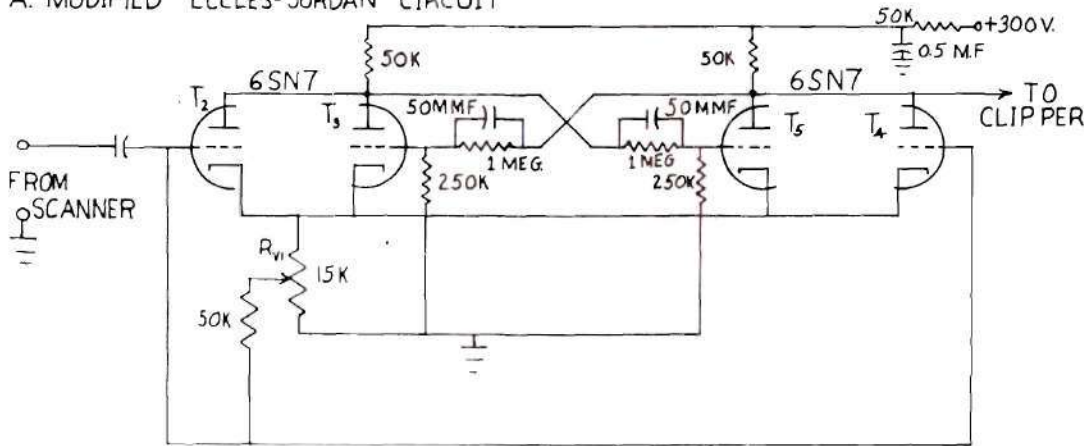
The Wave Shaper and Integrator. The positive pulses from the Scanner are used to trigger the modified Eccles-Jordan circuit shown in Figure 6(a). In this circuit, tubes T_2 and T_4 are trigger tubes which are normally cut off by a high negative bias. Tubes T_3 and T_5 with their associated circuit form the Eccles-Jordan circuit. When a positive impulse is applied to the grids of the trigger tubes, both of these tubes are turned on for an instant. As T_2 and T_4 begin to conduct, the voltages at the plates and at the grids of T_3 and T_5 suddenly drop. However, if T_5 is conducting and T_3 is cut off before the application of the pulse, the net effect of applying the pulse is to cut off T_5 and to turn on T_2 . When the next pulse comes along, the Eccles-Jordan circuit flips again and T_5 conducts. Consequently, an output voltage taken at the plate of T_5 is an approximately square wave with a width equal to the time difference between the pulses, T_n .

Since the output of the Eccles-Jordan circuit is not exactly a square wave, a four-stage clipper is employed to square the corners of the wave and to insure an essentially constant amplitude.

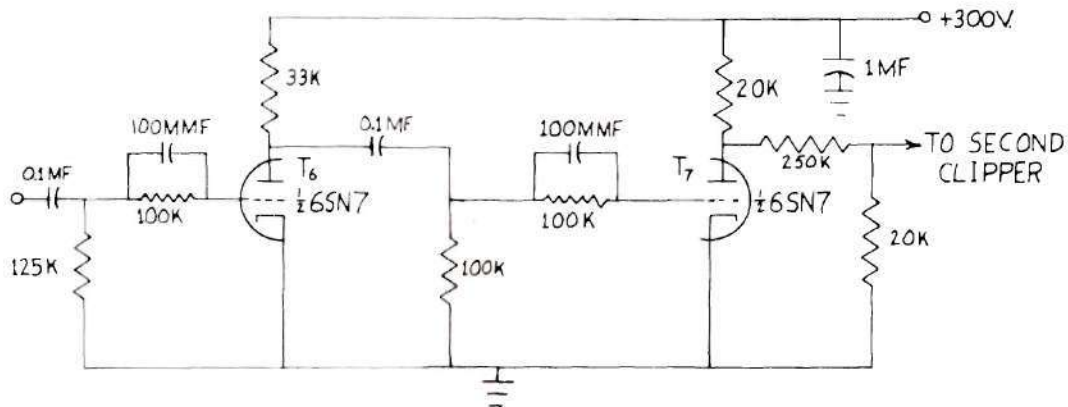
The First Clipper, shown in Figure 6(b), contains two stages of grid-limited triodes. The d-c component of the output voltage from the Eccles-Jordan circuit is removed by the input capacitor, so the voltage across the input grid resistor is a somewhat rounded square wave which alternates above and below ground potential. Since the grid of T_6 is at the zero-bias point before the signal is applied, the tube draws grid current during the time that the applied voltage is positive. Further-

FIGURE 6
WAVE SHAPER AND INTEGRATOR

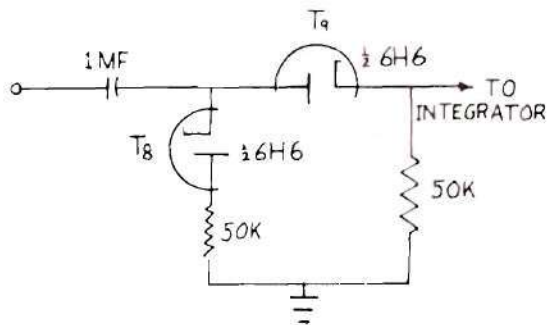
A. MODIFIED ECCLES-JORDAN CIRCUIT



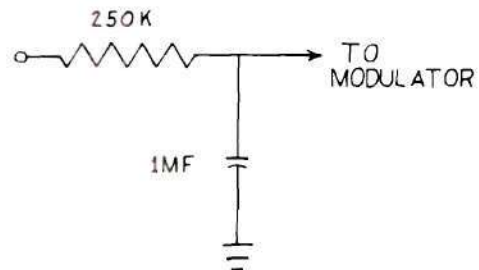
B. FIRST CLIPPER CIRCUIT



C. SECOND CLIPPER CIRCUIT



D. R C INTEGRATOR



more, the grid-to-cathode resistance of the tube is approximately 1000 ohms when the grid is positive. Therefore, when grid current flows, most of the input voltage is dropped across the 100,000-ohm resistor, and the grid voltage goes only slightly positive. On the other hand, the grid-to-cathode resistance of the tube is very high when the grid is negative with respect to the cathode. Consequently, the negative portion of the applied signal is faithfully reproduced at the grid of T_6 . The resultant output voltage at the plate of T_6 is given in Figure 5(c). Notice that the bottom of the wave is flattened by the grid limiting but the top is unchanged.

The circuit of tube T_7 operates in exactly the same manner as that of tube T_6 . Therefore, the output voltage at the plate of T_7 appears as shown in Figure 5(d).

The circuit of the Second Clipper is presented in Figure 6(c). After the d-c component of the voltage from the First Clipper has been removed by the input capacitor, the diodes T_8 and T_9 operate to eliminate the negative portion of the resulting wave. The output voltage of this circuit then appears as shown in Figure 5(e).

The RC Integrator illustrated in Figure 6(d) operates on the principle that the average voltage across the capacitor equals the average voltage of the applied wave. Furthermore, if the Integrator time constant is made very large as compared to the period of the applied wave, the capacitor voltage remains essentially constant. Since the Integrator time constant is approximately $300 T_k$, the output of the Integrator is a d-c voltage which has an amplitude proportional to the width of the square wave from the Second Clipper.

The Modulator. The Modulator consists of a Balanced Modulator, a frequency-sensitive Feedback Amplifier, and a two-stage Voltage Amplifier.

The Balance Modulator is shown in Figure 7(a). Under quiescent operating conditions, the plate voltages of tubes T_{10} and T_{11} are equal in magnitude and in phase. Therefore, the net voltage across the transformer primary is zero, and there is no output voltage at the secondary terminals. When a d-c voltage from the Integrator is applied to the grid of T_{10} , this tube conducts more than T_{11} . With unequal currents through T_{10} and T_{11} , the circuit is unbalanced, and there is an output voltage across the transformer secondary.

Since the output of the Balanced Modulator contains appreciable harmonics of the sixty-cycle input frequency, a frequency-sensitive Feedback Amplifier¹ is employed to eliminate these harmonics. This amplifier is shown schematically in Figure 7(b).

The voltage from the Feedback Amplifier is then applied to the Voltage Amplifier of Figure 7(c). The first section of this circuit is a conventional RC-coupled, Class-A amplifier. However, the second section is a paraphase amplifier. The function of the phase shifter in the output circuit of this latter amplifier will be apparent when the Divider is discussed.

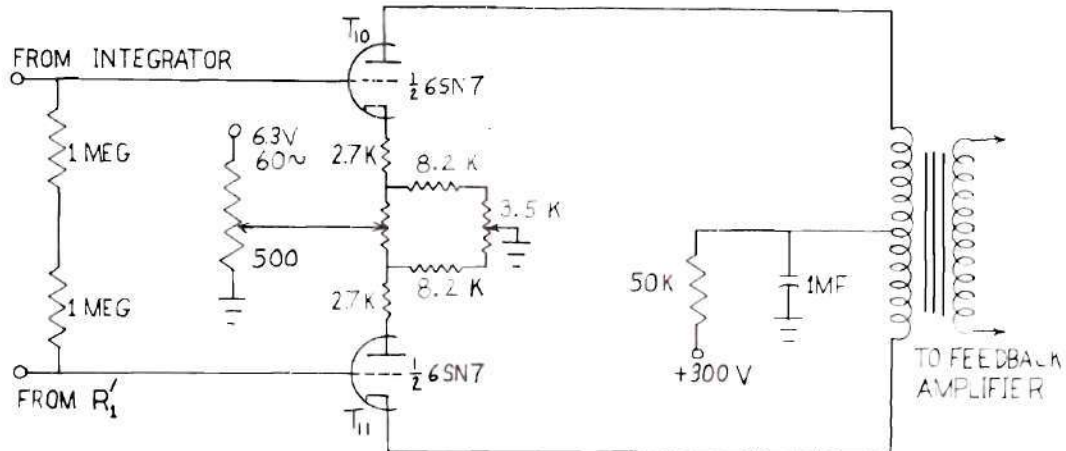
The Power Amplifier. The Power Amplifier,² illustrated in Figure 8, is driven by the Voltage Amplifier mentioned above. In this stage, the

¹L. Stanton, "Theory and Application of Parallel-T Resistance Capacitance Frequency Selective Networks," Proceedings of the Institute of Radio Engineers, 34:447-456, July, 1946.

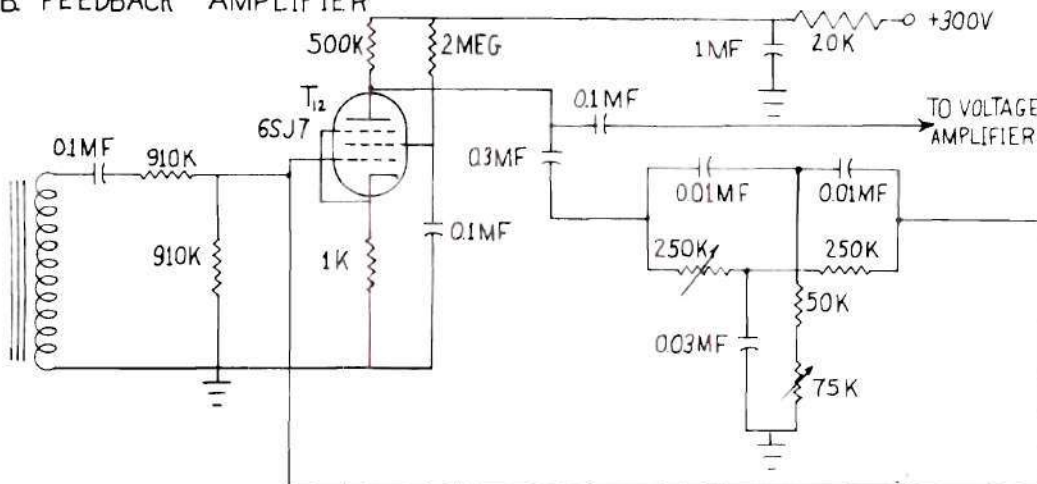
²This amplifier is a War Surplus item taken from an Army Radio SCR 545-A. (See Technical Supplement 1 to TM 11-1127, August 25, 1943.)

FIGURE 7
MODULATOR

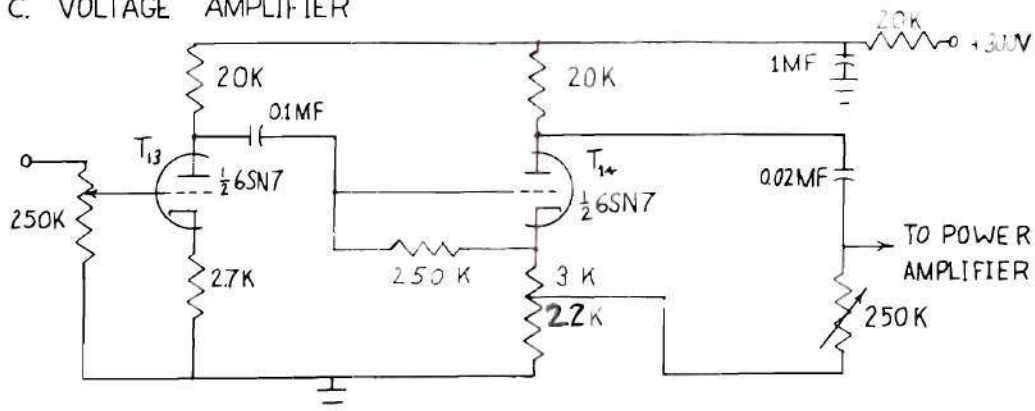
A. BALANCED MODULATOR

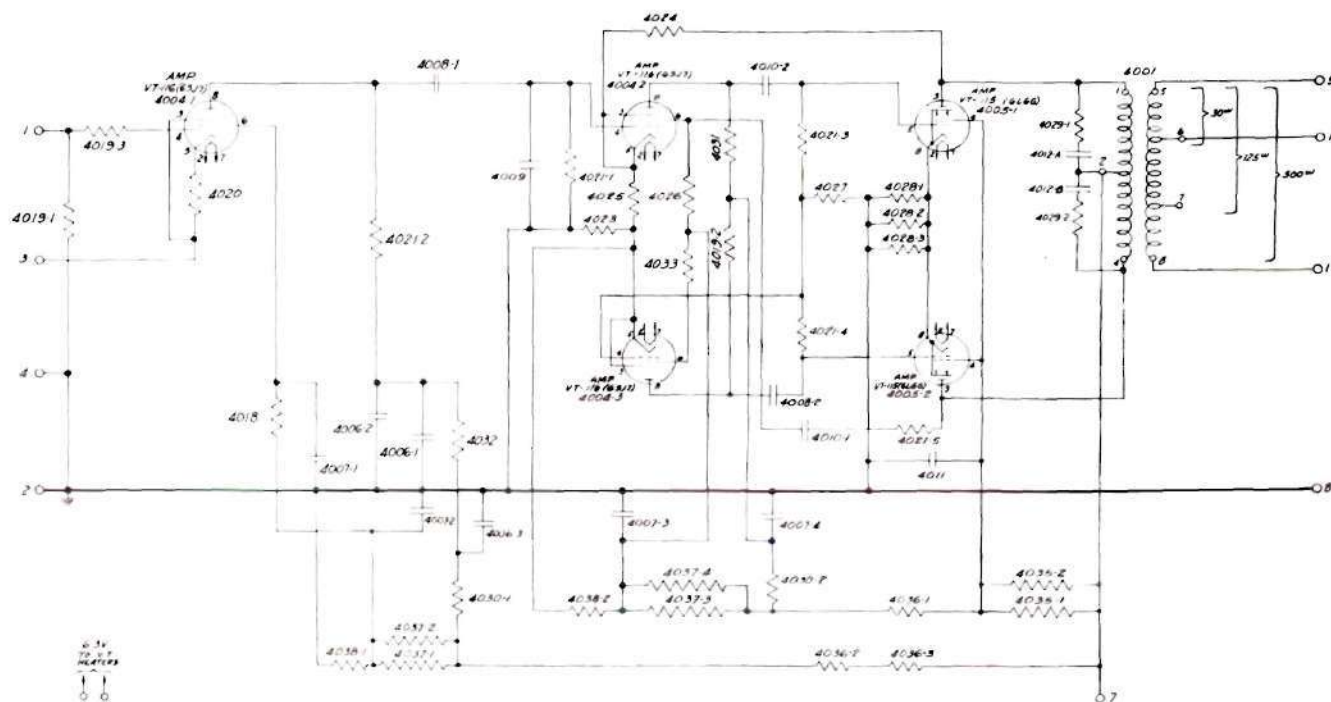


B. FEEDBACK AMPLIFIER



C. VOLTAGE AMPLIFIER





APP PART NO	ITEM ON DWG	QTY	DESCRIPTION	NAME	MADE BY OR EQUIVALENT	ADDRESS
4001	13 211 6415	1	RES 555	TRANSFORMER	WESTERN ELECTRIC CO	NEW YORK, N.Y.
4002						
4003				VACUUM TUBE 3		
4004	21 211 6415	3	RES 555	RES 555	RADIO CORPORATION OF AMERICA	CANON, N.J.
4005	24	2	RES 555	RES 555		
4006	24	2	RES 555	RES 555		
4007	24	2	RES 555	RES 555		
4008	24	2	RES 555	RES 555		
4009	24	2	RES 555	RES 555		
4010	24	2	RES 555	RES 555		
4011	24	2	RES 555	RES 555		
4012	24	2	RES 555	RES 555		
4013	24	2	RES 555	RES 555		
4014	24	2	RES 555	RES 555		
4015	24	2	RES 555	RES 555		
4016	24	2	RES 555	RES 555		
4017	24	2	RES 555	RES 555		
4018	24	2	RES 555	RES 555		
4019	24	2	RES 555	RES 555		
4020	24	2	RES 555	RES 555		
4021	24	2	RES 555	RES 555		
4022	24	2	RES 555	RES 555		
4023	24	2	RES 555	RES 555		
4024	24	2	RES 555	RES 555		
4025	24	2	RES 555	RES 555		
4026	24	2	RES 555	RES 555		
4027	24	2	RES 555	RES 555		

APP PART NO	ITEM ON DWG	QTY	DESCRIPTION	NAME	MADE BY OR EQUIVALENT	ADDRESS
4028	24	2	RES 555	RES 555		
4029	24	2	RES 555	RES 555		
4030	24	2	RES 555	RES 555		
4031	24	2	RES 555	RES 555		
4032	24	2	RES 555	RES 555		
4033	24	2	RES 555	RES 555		
4034	24	2	RES 555	RES 555		
4035	24	2	RES 555	RES 555		
4036	24	2	RES 555	RES 555		
4037	24	2	RES 555	RES 555		
4038	24	2	RES 555	RES 555		

FIGURE 8
POWER AMPLIFIER

power level is raised to that which is necessary to drive the positioning motor in the Divider. Since this circuit was not constructed by the author, no discussion of its operation is given.

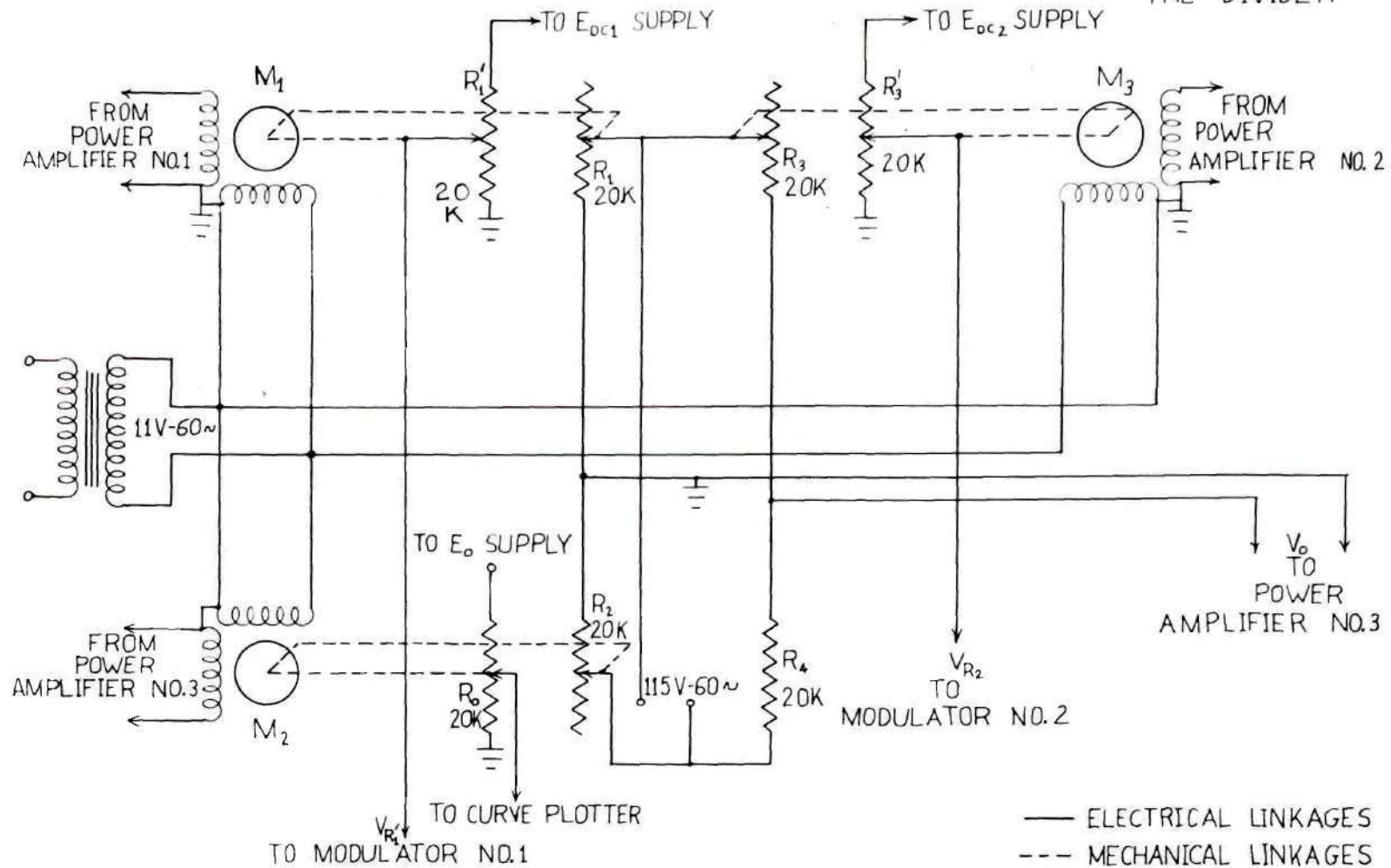
The Divider. The Divider is shown schematically in Figure 9. The operation of the positioning motors is considered first.

The positioning motors are two-phase, sixty-cycle, drag-cup motors rated at 11 volts and 0.7 amperes per phase. One field of each of these motors is excited by a constant 11-volt, sixty-cycle voltage which is obtained from a step-down transformer fed from the Main Power Supply. These fields are called the reference fields. The other fields, called the control fields, are excited by voltages which are ninety degrees out of phase with the reference excitation. Hence, the need for a phase shifter in the Modulator circuit.

The operation of motors M_1 and M_3 is identical, so only M_1 is considered here. The resistance R'_1 is a linear potentiometer which has its variable tap attached to the shaft of M_1 . A constant d-c voltage, E_{d-c} , is impressed across R'_1 . Therefore, the voltage between the variable tap point and ground is a linear function of the position of the shaft of M_1 , provided that no current is drawn from the tap point. Since the tap point of R'_1 is connected to ground through a 1-megohm resistor in parallel with the grid of T_{11} (see Figure 7), the current drawn from the tap is negligible compared with the current through R'_1 . Consequently, the voltage fed back to the Modulator is considered to be a linear function of the position of the shaft of M_1 .

Now, suppose that the voltage, V_{R1} , fed back to the Modulator in

FIGURE 9
THE DIVIDER



Channel 1 is less than the voltage output of the Integrator, V_{12} . This unbalances the Modulator and the resultant output voltage appears, greatly amplified, across the control field of M_1 . The polarity of the Modulator output is chosen so that M_1 rotates in the direction which increases the feedback voltage. When V_{R1} equals the Integrator output voltage, the Modulator is again balanced, and the control field voltage vanishes. Since the motor does not rotate unless both fields are excited, M_1 stops when V_{R1} equals V_{12} . If the Integrator output decreases, the Modulator output voltage reverses in polarity, and M_1 rotates in the opposite direction until V_{R1} again equals V_{12} .

In a similar manner, it may be shown that the motor, M_3 , operates so that V_{R2} equals the output of the Integrator in Channel 2.

Now, the potentiometers controlling the values of R_1 and R_3 in the Wheatstone Bridge are mechanically coupled to M_1 and M_3 respectively. Therefore, the resistances of two of the arms of the Bridge are proportional to the output voltages from the Integrators in Channels 1 and 2. Furthermore, the voltages from the Integrators are proportional to the ordinates of the curves. Consequently, the resistances of two of the arms of the Bridge are proportional to the ordinates of the two curves.

As previously mentioned, there is an output voltage, V_o , obtained from the Wheatstone Bridge when the Bridge is unbalanced. This voltage is shifted in phase and amplified by Power Amplifier No. 3. It is then applied to the control field of M_2 . This motor positions the potentiometer which controls R_2 , the third variable arm of the Bridge, so as to rebalance the Bridge. When the balance position is reached, V_o vanishes and M_2 stops.

Further examination of Figure 9 reveals that the output potentiometer, R_o , is connected to the shaft of M_2 . A constant d-c voltage is impressed across R_o so that the voltage output from the variable tap is directly proportional to the resistance between this tap and ground, provided that negligible current is drawn from the tap. Therefore, the output voltage is proportional to R_2 , which is, in turn, proportional to the ratio of the ordinates of the input curves.

The Curve Plotter. The input impedance of the Curve Plotter should be high in order that negligible current will be drawn from the tap on R_o . Therefore, a recording d-c voltmeter with a high input impedance should be used to plot the output curve. Since a suitable instrument was not available, and since time did not permit the construction of circuits which would allow the use of existing equipment, the output curves were not recorded.

Power Supplies.

A. Main Power Supplies. The Main Power Supply for Channel 1 is illustrated in Figure 10.³ This circuit is fed from the 110-volt, 60-cycle line. It produces a regulated, 300-volt, d-c voltage.

Since this circuit was not constructed by the author, no discussion of its operation is given.

An identical unit is employed to supply power to Channel 2.

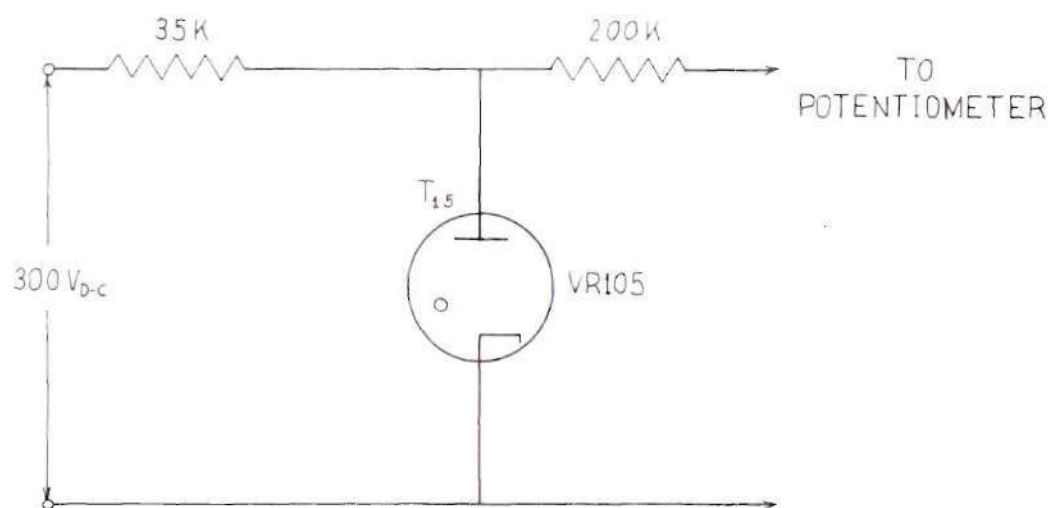
³This is a War Surplus item taken from an Army Radio Set, SCR 545-A.

B. Low Voltage D-C Supplies. The voltages E_{d-c1} , E_{d-c2} , and E_o are supplied to potentiometers R'_1 , R'_3 , and R_o respectively, by identical circuits. One of these supplies is shown in Figure 11.

The input to these circuits is taken directly from the Main Power Supplies. The output voltages are held approximately constant by the VR-105 tubes.

C. Reference Field Supply. It may be seen from Figure 9 that the motor reference fields are supplied by a step-down transformer. This transformer produces the required 11-volt excitation when fed from the 110-volt line.

FIGURE 11
LOW VOLTAGE D-C SUPPLY



CHAPTER IV

PERFORMANCE AND CONCLUSIONS

In the preceding chapters, a computer which would calculate the desired ratio curves was proposed, and the circuits constructed to date were described. Unfortunately, time did not permit the assembly of the entire system. Consequently, the present chapter shall be devoted to an evaluation of the units completed and to recommendations for improvement of these units.

The Scanner. All of the components of both Scanners were constructed. However, time did not permit the assembly of a complete Scanner. Since the completion of these units is primarily a mechanical problem, no major difficulties are anticipated.

The lack of a Scanner forced the author to employ available equipment to simulate the Scanner output pulses.

The Wave Shapers and Integrators. The performance of the Wave Shapers and Integrators is indicated by the results of Test 1 in Appendix A. In this test, the input voltage was obtained by differentiating the output voltages of two square-wave generators connected in parallel. Both of the square-wave generators were synchronized with a 1200-cycle audio oscillator. However, a phase shifter was inserted in the synchronizing circuit of one of these generators so that the square waves from this generator could be delayed with respect to the waves from the other generator. The output voltage of the differentiator was then a series of alternate positive and negative pulses. But, the negative pulses do not trigger the Eccles-Jordan circuits, so they may be ignored. The time

between the odd numbered positive pulses was constant as was the time between the even numbered positive pulses. However, the time between the first and second positive pulses, the third and fourth positive pulses, etc., depended on the delay introduced by the phase shifter. Consequently, the input voltage simulated the output voltage of a Scanner. (See Figure 5.)

The time between the initiating and the terminating pulses, T_n in Figure 5, was measured by comparing the distance between these pulses with the distance between two initiating pulses on the screen of a cathode-ray oscilloscope. The time between two succeeding initiating pulses was 833 microseconds. This method of measurement may introduce appreciable errors since it is impossible to determine the exact instant when the pulses occur.

Figure 12 (a) shows the output voltages of the Integrators as a function of T_n , the time between the initiating and terminating pulses. In spite of the anticipated error in measuring T_n , it is seen that the variation of these voltages with T_n is approximately linear as predicted in Chapter 3.

The Modulators and the Divider. The Modulators and the Divider were tested under simulated operating conditions. The results of this test are shown as Test 2 in Appendix A.

In Test 2, the input to the Wave Shapers was a series of pulses obtained from a square-wave generator in the manner described above. The time between the positive pulses was held constant at 417 microseconds. The output of the Channel 2 Integrator was held constant at 2.18 volts while the output of the Channel 1 Integrator was varied from 2.00 volts

to 1.30 volts. The variation of this latter voltage was obtained by adjusting the "Output Voltage Control" knob on Chassis 1-1.

If the system followed the theoretical behavior perfectly, the resistance of the balancing arm of the Bridge would be directly proportional to the ratio of the d-c voltages applied to the Modulators, i.e., $R_2 = k \frac{V_{11}}{V_{12}}$. It may be seen from the results of Test 2 that the proportionality factor, k , does not remain fixed for all ratios of the input voltages. However, the random variation of k may well be caused by the difficulty encountered in attempting to reproduce exact settings on the coarse potentiometers employed in the Divider. It is recommended that multiple-turn potentiometers be substituted for the single-turn potentiometers which are incorporated in the present system. Highly accurate multiple-turn potentiometers are manufactured by both the Helipot Corporation and the Thomas L. Gibbs Company.

During Test 2, it was found that motors M_1 and M_3 operated satisfactorily with the present position control system. However, the motor M_2 , controlling the balancing arm, would often overshoot the balance point and then oscillate for three or four cycles before coming to rest. The use of precision potentiometers should reduce this hunting considerably.

Summary. The overall performance of the system constructed indicates that the proposed computer will operate as predicted.

The accuracy of the present device may leave much to be desired. However, ideal performance can hardly be expected from a first model which was, of necessity, designed to employ equipment on hand.

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BIBLIOGRAPHY

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APPENDICES

APPENDIX A

TEST RESULTS

Test 1. Performance of Wave Shapers and IntegratorsTest Equipment.

Measurements Corporation Square-Wave Generator - Model 71

RC Differentiator - $R = 2700$ ohms $C = 100$ mmf.

Hewlett-Packard VTVM - Model 410-A

Hewlett-Packard Audio Oscillator - Model 200 B

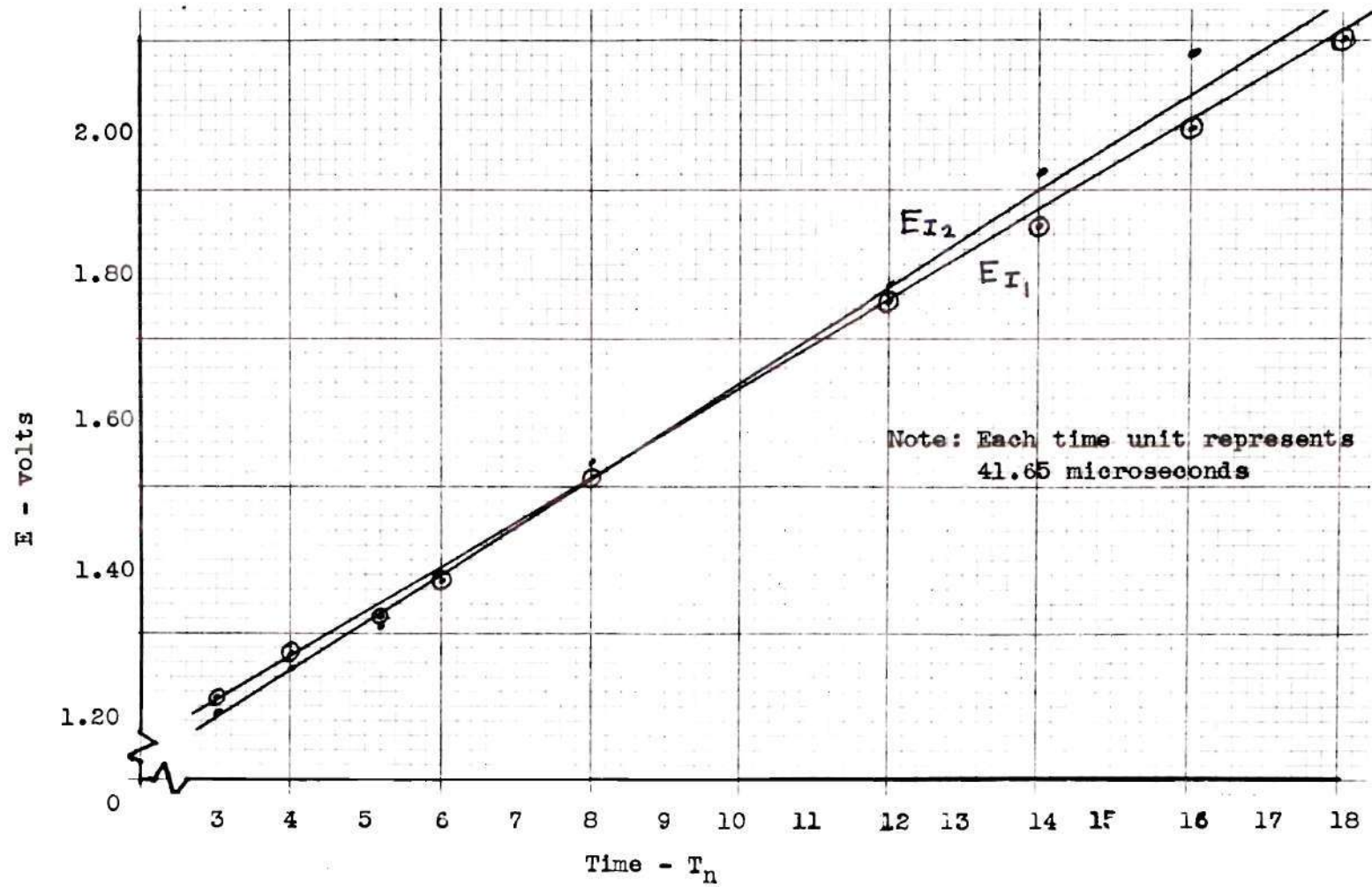
$$T_k = 833 \text{ microseconds}$$

$$T = \frac{T_k}{20} = 41.65 \text{ microseconds}$$

T_n microseconds	E_{I_1} volts	E_{I_2} volts
3T	1.21	1.19
4T	1.27	1.25
5T	1.32	1.31
6T	1.37	1.37
8T	1.51	1.53
12T	1.75	1.77
14T	1.85	1.92
16T	1.98	2.08
18T	2.10	2.21

FIGURE 12 (a)

PERFORMANCE OF WAVE SHAPERS AND INTEGRATORS



Test 2. Performance of Modulators and Divider

Test Equipment

Measurements Corporation Square-Wave Generator - Model 71

RC Differentiator R = 2700 ohms C = 100 mmf.

Hewlett Packard VTVM - Model 410-A

Note: T was held constant at 417 microseconds.

All voltages were read from the d-c scales of the VTVM.

All resistances were read from the ohms scales of the VTVM.

$$r = \frac{V_{R2}}{V_{R1}} \quad k = \frac{R_2}{r}$$

V_{R2} volts	V_{R1} volts	r	R_2 ohms	k	$\frac{k}{k_{avg.}}$
2.18	2.00	0.917	17000	18500	0.980
2.18	1.89	0.867	16300	18800	0.994
2.18	1.79	0.822	15000	18200	0.980
2.18	1.71	0.786	15000	19100	1.01
2.19	1.60	0.730	13800	18900	1.00
2.16	1.54	0.713	13600	19100	1.01
2.17	1.36	0.627	12000	19100	1.01
2.16	1.32	0.612	12000	19600	1.04
2.19	1.30	0.593	11000	18600	0.985

APPENDIX B

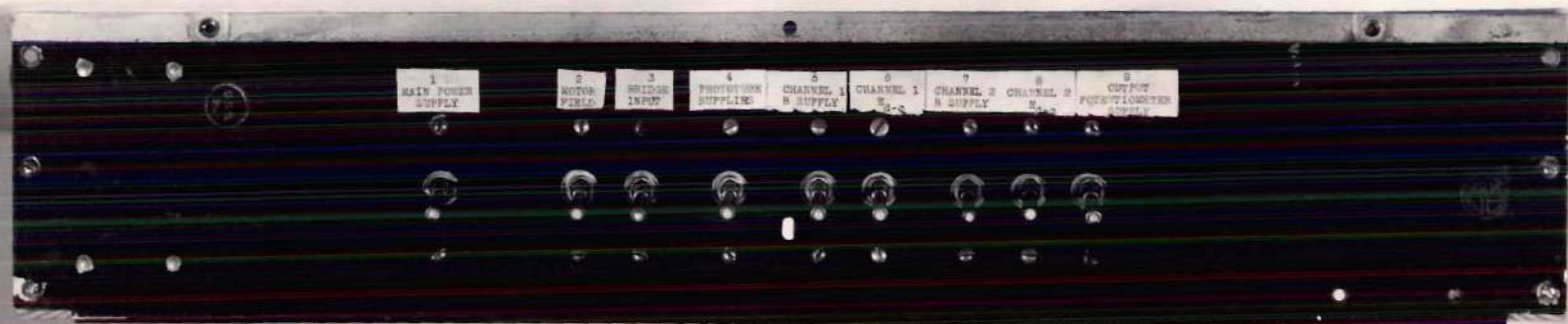
OPERATING INSTRUCTIONS

A photograph of the Main Switch Panel is shown in Figure 12.

The recommended operating procedure is as follows:

1. Insert the input curves in the Scanners so that they will be scanned from left to right.
2. Turn on switch 1. This connects the 110-volt a-c line to the Main Power Supplies. The heaters of all tubes, except those in the phototube circuits, are also energized by this action.
3. After a five-minute warm-up period, close switches 2, 4, 5 and 7. The Input Networks, exclusive of the Scanners, are now ready for operation, and the motor reference fields are energized.
4. Turn the switches located on the front panels of the Wave Shapers to "Test." If the neon lamps light, the Eccles-Jordan circuits are in their correct operating condition. If one, or both, of the lamps does not light, push the appropriate button on the front of the Wave Shaper. This action causes the current to shift to the correct tube. If the incorrect condition occurs frequently or repeatedly, reverse the tubes in the Eccles-Jordan circuit.
5. Close switches 6 and 8. If E_{d-c1} and E_{d-c2} are other than zero, the Modulators are then unbalanced. Consequently,

FIGURE 12
MAIN SWITCH PANEL



- M_1 and M_3 will turn until the above voltages are zero.
6. Turn on the light sources and the synchronous motors in the Scanners by closing the proper switches on the side of Scanner No. 1.
 7. Slide off the cover plates on Scanners 1 and 2, thus allowing the scanning beams to reach the phototubes. M_1 and M_3 now turn until the voltages from R'_1 and R'_3 are equal to the voltages from the Integrators.
 8. Close switch 3. If R_2 is not equal to R_4 , M_2 turns until this equality is established.
 9. Close switch 9.
 10. Close the X-Motion Drive Motor switch. (This switch should also control the drive motor for the output curve.) The device now begins to compute and plot the desired curve.
 11. When the input curves have been completely scanned, perform the above operations in reverse order.

APPENDIX C

MAINTENANCE INSTRUCTIONS

From time to time the system should be checked in order to insure proper operation. A list of some of the possible faults together with suggested remedies is given below.

1. The output voltages from the Integrators may become unequal although curves of equal amplitude are being scanned. Turn the "Output Voltage Adjust" knob on the front of Chassis 1-A until the desired equality is established.
2. The Eccles-Jordan circuits may fail to fire properly. Adjust the "Bias Control" knob on the appropriate chassis.
3. One of the Modulators may become unbalanced thus causing an inequality between the output voltages of the corresponding Integrator and motor control potentiometer. Adjust the balancing controls on the front of the Modulator chassis.
4. One of the motors may fail to turn in spite of the presence of an appreciable voltage across the control field. First, check the reference field input. If this latter voltage is correct, the difficulty is probably caused by an improper phase relationship. Use a CRO to check the phase angle between the reference field voltage and the control field voltage. If there is not a ninety-degree phase difference, adjust the "Phase Control" on the front of the Modulator.
5. One of the motors may suddenly start oscillating. This is

generally caused by too much gain in the feedback loop. Use the "Output Voltage Adjust" on the front of the proper Modulator to reduce this gain.

If the device continues to function improperly after the suggested corrective measure has been applied, the fault should be localized by testing the input and output of each unit. When the faulty unit has been located, it must then be removed from the system and repaired.

As a general check on system performance, tests similar to those described in Chapter IV may be performed.